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Environmental correlates of adiposity in 9-10 year old children: considering home and school neighbourhoods and routes to school

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Abstract

The rapid speed of the recent rise in obesity rates suggest environmental causes. There is therefore a need to determine which components of the environment may be contributing to this increase. In this cross-sectional study, we examined the associations between adiposity and the characteristics of areas around homes, schools and routes to school among 1995 well-characterised 9-10 year old boys and girls in Norfolk, UK. The relationships between Fat Mass Index (FMI, calculated as fat mass (kg)/height(m)²) and objectively computed environmental indicators describing access to food outlets and physical activity facilities, the safety and connectivity of the road network, and the mix of land uses present were investigated. Multivariable hierarchical regression models were fitted with log-transformed FMI as the outcome, and stratification by gender and mode of travel to school. Among girls, better access to healthy food outlets (supermarkets and greengrocers) in the home environment was associated with lower FMI while better access to unhealthy outlets (takeaways and convenience stores) around homes and schools was associated with higher FMI. Also in girls, a higher proportion of accessible open land and a lower mix of land uses around the school were associated with higher FMI. Among boys the presence of major roads in the home neighbourhood was associated with higher FMI among non-active travellers, while major roads in the school neighbourhood were associated with lower FMI among active travellers. No significant associations were seen between FMI and any of the route characteristics. While the relative paucity of associations provides few indicators for the design of effective interventions, there was some evidence that environmental characteristics may be more important among active travellers than non-active travellers, and among girls than boys, suggesting that future interventions should be sensitive to such differences.

Introduction

The speed of the recent rise in the prevalence of obesity suggests that some components of the environment may have an aetiological role (Hill, Wyatt, Reed, & Peters, 2003). The term ‘obesogenic environment’ has been coined to describe those environments which may

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promote the acquisition of excess fat mass (Egger & Swinburn, 1997). The areas in which children live, study and play may promote or inhibit physical activity, and can provide opportunities for the consumption of both healthy and unhealthy foods (Swinburn, Egger, & Raza, 1999), factors which play key roles in the development of excess body fat.

Despite growing interest in environmental determinants of obesity, few studies have examined associations between adiposity measures and environmental factors in children. Those that have tend to focus on specific elements of the home neighbourhood environment relating to either food or physical activity, but rarely both. The neighbourhood food environment is thought to act on eating behaviours and adiposity via the opportunities to obtain food, while facilities provision, accessibility and community design are aspects of the environment thought to impact on physical activity (Townshend & Lake, 2009).

Results from studies considering access to food outlets and adiposity measures in children have been mixed. Living nearer to a supermarket has been associated with a decreased risk of obesity (Liu, Wilson, Qi, & Ying, 2007), while higher BMIs have been seen among children living near to a convenience store (Galvez, et al., 2009). However, Crawford et al (Crawford, et al., 2008) found the number of fast-food outlets within 2km of the home was inversely associated with BMI among 13-15 year old girls, while Sturm & Datar (2005) reported no association between children's BMI and density of grocery stores, convenience stores, full-service restaurants, or fast-food restaurants in the home neighbourhood, and Burdette & Whitaker (2004) observed no relationship between overweight and access to fast-food restaurants among low-income pre-school children.

Studies examining physical activity environments have seen similarly mixed results. Some significant associations have been observed, with lower odds of being overweight seen among children with increasing numbers of physical activity facilities near their homes (Gordon-Larsen, Nelson, Page, & Popkin, 2006), and higher odds of overweight and obesity among those living in neighbourhoods with fewer amenities (sidewalks, parks, playgrounds, recreation centres, community centres and libraries) (Singh, Siahpush, & Kogan, 2010). Others have found associations vary by age groups. Timperio et al (2005) found significant associations between parental perception of the home environment (perceived heavy traffic on local streets was associated with higher odds of overweight and obesity) and the odds of being overweight in older (10-12 year olds), but not younger children (5-6 year olds).

In one of the few studies to have examined associations between neighbourhood characteristics and change in adiposity, Timperio et al (2010) found that an increase in the number of 4-way intersections in a neighbourhood, defined by an 800m radius around the home, was associated with a decrease in BMI z-score among younger children (aged 5-6 years old at baseline), while among older children (aged 10-12 years old) length of access paths (overpasses, access lanes and throughways between buildings) within 800m of their home was positively associated with change in BMI z-score. However, Franzini et al (2009) found no associations between measures of the built environment (traffic flow, vandalism, residential density and land use mix) and BMI, and while they saw significant association with physical activity outcomes, Norman et al (2006) found no significant associations between community design or access to recreational facilities and BMI (Norman, et al., 2006).

Previous reviews have highlighted the need to include a wider range of environmental characteristics (e.g. to measure aspects of food and physical activity environments) (Dunton, Kaplan, Wolch, Jerrett, & Reynolds, 2009), and to consider environments beyond the home neighbourhood (A. Jones, Bentham, Foster, Hillsdon, & Panter, 2007; van der Horst, et al., 2006). As children attend school on the majority of days of the year, it has been suggested

that school neighbourhoods may be important (Swinburn, et al., 1999). For example, Davis et al (2009) recently found that pupils attending schools with a fast-food restaurant nearby were more likely to be overweight or obese. The characteristics of a child's route to school may also influence risk of obesity. They may promote or inhibit walking or cycling, both commuting behaviours that can make significant contributions to overall physical activity (van Sluijs, et al., 2009). Routes to school may also provide opportunities to use food outlets and other facilities.

This cross-sectional study aims to identify objectively measured aspects of children's environments that are associated with adiposity in 9-10 year old children. We consider the availability of food outlets and physical activity facilities as well as road safety, connectivity and land use mix in home and school neighbourhoods and along routes to school. We hypothesise that the influence of environmental factors may be different in girls and boys, and could be greater among those who spend more time travelling on foot or by bicycle due to greater exposure to the environment in these groups, compared to those in vehicles. Hence we further investigate whether associations vary by gender and mode of travel to school. The study utilises a well characterised sample of children living and studying in environmentally heterogeneous locations in the county of Norfolk, England, among whom we have previously examined associations between the food environment of home neighbourhoods and food consumption, and school environments and physical activity (Skidmore, et al., 2009; van Sluijs, et al., 2010).

Methods

Study methods and recruitment

The SPEEDY study (Sport, Physical activity and Eating behaviour: Environmental Determinants in Young people) was instigated to investigate individual and collective correlates of diet and physical activity behaviour of school Year 5 (9-10 year old) pupils across the county of Norfolk, UK. The study's methods are described in detail elsewhere (van Sluijs, et al., 2008) and so are only briefly recounted here.

Schools across Norfolk with at least 12 Year 5 pupils were sampled stratified by urban/rural status (Bibby & Shepherd, 2004). Invitations to participate were sent at random to 157 of the 227 eligible schools, of which 92 agreed to take part in the study. Research assistants visited participating schools to introduce the study to all Year 5 children. Children were given an information pack containing a leaflet for themselves, a letter for their parents/guardians, and a consent form. Only children with a consent form signed by both a parent/guardian and the child on the day of measurement were included in the study. In total 2064 children were recruited into SPEEDY (57.0% response rate). Ethical approval for the SPEEDY study was obtained from the University of East Anglia local research ethics committee in December 2006.

Child measurement

Data collection was undertaken during the summer term (April-July) of 2007. A range of anthropometric measurements were undertaken by trained research assistants using standardized procedures. Height was recorded to the nearest millimetre using a Leicester height measure. Non-segmental Tanita scales (type TBF-300A) were used to measure foot-to-foot bioelectrical impedance. This technique sends a small electrical current through the individual, giving an 'impedance' value indicating the degree to which the current was impeded by the body. As this is dependant on the composition of the body (largely the proportion of fat), equations (Tyrrell, et al., 2001) have been derived through which fat mass (FM) can be determined. As it is the acquisition of excess fat in the body, rather than weight,

that constitutes a health risk, this measure is seen as preferable to weight-based measures of adiposity such as BMI. As FM is related to height (VanItallie, Yang, Heymsfield, Funk, & Boileau, 1990) Fat Mass Index ($FMI = FM(kg)/height(m)^2$), was calculated for each child for whom height and impedance data were available. FMI was seen to correlate better with physical activity than other adiposity measures among this sample (Steele, van Sluijs, Cassidy, Griffin, & Ekelund, 2009).

Each child's gender and date of birth were recorded at the anthropometric measurement visit. On the same day, participating children were asked to complete a questionnaire about their home, physical activity, and eating habits, which included a question asking how they usually travelled to school (on foot, by bicycle, by car, or by bus or train). Children were given a pack to take home which included a questionnaire for their parents or carers to complete and return to the school.

As family socio-economic status has been associated with child weight status (Danielzik, Czerwinski-Mast, Langnase, Dilba, & Muller, 2004), we included a measure of it as a co-variate in all models. The variable was derived from the parent questionnaire, which was completed by the mother on 84% of occasions. Four measures of SES were recorded; home ownership, car ownership, the age the parent left full-time education, and their highest educational qualification achieved. The last of these was the only one to show a statistically significant association with FMI in this sample and so was used in these analyses. Answers to this question were grouped into four categories; no qualifications/school leaving certificate, GCSE (the national school exams in England and Wales, usually taken at age 16) or equivalent, A'Level (the national school exams in England and Wales, usually taken at age 18) or equivalent, and degree or higher.

Defining environments

Three environments were investigated in this study; the home neighbourhood, school neighbourhood, and modelled route between home and school. Participants were asked to provide their home address on the consent form. Map grid references were determined for valid addresses from a lookup table (Ordnance Survey, 2007c), providing the precise location of each child's home. An on-foot grounds audit was undertaken at all participating schools (N. R. Jones, et al., 2010), and this identified the location of all entrances to the school grounds. For this analysis, the entrance closest to the main school building was used as the school's location for the purpose of defining the school neighbourhood.

Neighbourhoods around homes and schools were defined as the area within 800m (roughly a 10 minute walk) along a pedestrian network. While the definition of subject-specific neighbourhoods is seen as preferable to the use of existing administrative boundaries (Ball, Timperio, & Crawford, 2006), there is no agreement on the parameters used to define these neighbourhoods. Indeed, these may vary from location to location and person to person. We selected a distance of 800m to define our neighbourhoods as this distance has been used previously in the study of school neighbourhood food environments (Austin, et al., 2005) and features in this size of neighbourhood have also shown more associations with adiposity and physical activity outcomes than those of larger (2km) neighbourhoods (Timperio, et al., 2010). The pedestrian network was derived from the Ordnance Survey's Integrated Transport Network (Ordnance Survey, 2007a), which describes Great Britain's road structure, to which public rights of way (footpaths, bridleways), were added. Neighbourhoods were delineated from this network using the ArcGIS 9.2 package (ESRI Inc, 2005). No information was available on the actual route each child took to school, and therefore predicted routes were modelled based on the assumption that children would take that which equated to the shortest distance. The network was interrogated to identify the roads comprising the shortest distance route between each child's home and the closest

access point to their school. As each route was represented by a linear feature, the route environment was defined as the area falling within 100m of the route line, a distance felt sufficient to describe the environment proximal to the route, and one that has been used in previous work on this sample (Panter, Jones, Van Sluijs, & Griffin, 2010).

Characterising Environments

Once the three environments had been delineated, a set of variables was derived to describe them. We selected measures which described characteristics of the environment that had previously been hypothesised or seen to be associated with obesity and its determinants: access to food outlets (Rundle, et al., 2009) and physical activity facilities (Gordon-Larsen, et al., 2006), the safety and connectivity of the road network (Rutt & Coleman, 2005), and the mix of land uses present (Frank, Andresen, & Schmid, 2004).

Our environmental measures were derived mostly from Ordnance Survey (OS) data. OS is Britain's national mapping agency and maintains national, widely adopted datasets describing the road network, land cover, and the location of residential and commercial addresses. The locations of food outlets and physical activity facilities were derived from the OS Points of Interest (POI) dataset (Ordnance Survey, 2007d). POI details the location of around 4 million facilities and classifies them into over 600 groups. Location and classification details are based on information provided by over 150 suppliers including Royal Mail, Thompson directory (a local telephone directory), and some individual restaurant chains. (Ordnance Survey, 2007d)

Accessible open land was defined as any green space freely accessible to the general public, including municipal parks, nature reserves, country parks and public woodland. Major roads included all 'A' class roads. These are the main recommended routes between and through larger settlements, and can be either single or dual carriageway with speed limits of up to 70 miles per hour. Details of all environmental variables and the data and methods used to derive them are given in Table 1.

Many of our home and school neighbourhoods had few or no food outlets and physical activity facilities within their boundaries, and children and their parents may hence travel outside the neighbourhood to make use of them. We therefore computed accessibility measures that were independent of the neighbourhood boundary; the accessibility of these facility types was calculated as a weighted sum of the distance to every facility within 6km of each home and school:

$$A_i = \sum_j 1/d_{ij}^p$$

Where A_i is the measure of accessibility of a given facility type from location i (either a home or school), d_{ij} is the distance from location i to facility j , and p is a distance decay parameter, here set at 2, a value suggested as appropriate for this form of analysis (de Smith, Goodchild, & Longley., 2007) in the absence of the empirical data required to determine a sample-specific figure. The 6km cut-off was imposed as the impact of any outlet to the overall accessibility score reduces with increasing distance, so outlets at distances beyond this point have a negligible impact on the score. Food outlets were classified as healthy (supermarkets and greengrocers) or unhealthy (convenience stores and takeaways) using the typology of Rundle et al (2009). Physical activity facilities included community centres and sports facilities.

Statistical analysis

All statistical analyses were performed using Stata IC version 11 (StataCorp, 2009). The outcome variable, FMI, was log transformed as its distribution was skewed. To take account of the hierarchical nature of the dataset (children nested within schools) random effects multi-level regression models were used (xtreg command in Stata). Many of the environmental variables were not normally distributed, or had limited ranges, so they were grouped into tertiles and analysed as categorical variables, with a test for trend. For several of the variables it was not possible to define tertiles, so a presence/absence classification was used. As gender differences have been observed in physiological and environmental determinants of adiposity (Wisniewski & Chernausek, 2009), all analyses were undertaken separately for girls and boys in each environment (home/school/route). Initial models were run with all environmental variables and the co-variables age and parent's highest educational qualification included, with the least statistically significant environmental variables being removed until only those significant at $p < 0.05$ remained. To avoid obtaining potentially spurious differences in the predictors of FMI across the three environments due to multiple tests, any variable found to be significantly associated with FMI in one of the three environments was then added back into the models for the other two so its effect could be tested.

Once final models were reached, the moderating effect of mode of travel to school was investigated by entering interaction terms for mode of travel (comparing those walking or cycling to school with those travelling by car, bus or train) and each environmental variable present in the final models. Where interaction terms were associated at $p < 0.1$, they were further investigated in stratified models.

Results

Amongst the 2064 children who agreed to take part and were included in the SPEEDY study, valid height and impedance data were available for 2047 participants. A further 52 were excluded as 41 did not provide valid home addresses and 11 did not report their usual mode of travel to school. To prevent further loss of cases, values for the 168 participants missing information on parent's highest educational qualification were imputed to the modal value (GCSE or equivalent). This resulted in a final sample of 1995 children. There was no significant difference in FMI between those included and excluded (mean (standard deviation) log-transformed FMI for those included = 1.67 (0.41), and excluded = 1.61 (0.41), $p = 0.299$).

Summaries of the characteristics of the pupils included in these analyses are shown in Table 2. There were slightly more girls (55%) than boys, and girls generally had higher FMI scores than boys ($p < 0.05$). A higher percentage of girls than boys walked to school, but boys were more likely to cycle (both $p < 0.05$).

In the final multivariable models, age was positively associated with FMI, but the association only reached statistical significance among active-travelling girls in the school neighbourhood. Parent's education showed a negative relationship with FMI, with particularly large effects seen among non-active travelling boys. Four environmental variables showed statistically significant associations with FMI for girls (Table 3). The strongest associations are seen among those who walk or cycle to school. In the home environment better access to healthy food outlets is associated with lower FMI among active travellers (those who walk or cycle), while better access to unhealthy food outlets is associated with higher FMI in both groups. In the school environment, statistically significant associations are only seen among active travellers, with higher FMI among those with better access to unhealthy food outlets and more accessible open land, and lower FMI

among girls attending schools surrounded by more mixed land use. In the route environment, no environmental variables remain significantly associated with FMI. Associations appear to operate in the same direction as in the home and school environments but effect sizes are small and associations are non-significant.

For boys (Table 4), the presence of a major road in the home environment is associated with higher FMI among non-active travellers. Among active travellers, the association operates in the opposite direction, but is only statistically significant in the school environment. No other statistically significant associations were observed.

Discussion

We investigated how objectively measured aspects of home, school and route environments were associated with 9-10-yr old children's FMI. We found significant associations between FMI and a number of environmental characteristics, but these varied by sex, mode of travel to school and setting.

For girls, the strongest associations we observed were among those walking or cycling to school. In this group lower FMI was seen among those with better access to healthy food outlets, and higher FMI among those with better unhealthy food access in the home environment. The association with unhealthy food outlets was also seen among active travellers in the school neighbourhood. Similar relationships between access to food outlets and adiposity have been observed elsewhere in adults (Morland, Diez Roux, & Wing, 2006; Rundle, et al., 2009; Wang, Kim, Gonzalez, MacLeod, & Winkleby, 2007), and to some extent in children (Davis & Carpenter, 2009; Liu, et al., 2007). In this sample, children living closer to supermarkets have been found to consume more fruit and vegetables, while those living closer to convenience stores consume more crisps, chocolate and white bread (Skidmore, et al., 2009). However, little longitudinal evidence is available from which the direction of causality may be determined (White, 2007), and there is also some evidence that unhealthy food outlets may be more likely to be sited in areas which already have a higher prevalence of overweight children (Macdonald, Cummins, & Macintyre, 2007). Furthermore, we do not know why these associations were not also observed among boys, especially as boys were more heterogeneous than girls in FMI (standard deviation of log-transformed FMI was 0.38 among girls and 0.41 in boys).

The finding that girls attending a school with a greater proportion of accessible open land around it had a higher FMI does not operate in the direction we expected. Parks and green spaces are seen as potential venues for physical activity (Bedimo-Rung, Mowen, & Cohen, 2005), and so we had expected their presence to be associated with lower FMI. However they may also impact on parents' and children's perceptions of neighbourhood safety. As open spaces, especially wooded or naturalistic ones, can be perceived as unsafe (Jorgensen, Hitchmough, & Calvert, 2002; Özgüner & Kendle, 2006) they may discourage children and their parents from using them, and the area around them. Investigating the mediating steps in the relationship between accessible open land and FMI would require information on the actual use of accessible open land around schools, which we do not have.

Also for girls, lower FMI was observed in active travellers with a greater land use mix in the school neighbourhood. Land use mix has previously been reported to be both positively (Rutt & Coleman, 2005) and negatively (Frank, et al., 2004; Rundle, et al., 2009) associated with adiposity among adults. It is often used as a measure of the degree to which residential and non-residential zones mix and thus as an indicator of the on-foot accessibility of locations that are commonly visited, such as schools, employment locations, and shops (Grant, 2002). However, the variable was also employed as a measure of the visual variety

in the landscape, which has been shown to encourage walking in adults (Craig, Brownson, Cragg, & Dunn, 2002). Little work has been done to investigate how land use mix may impact on children's physical activity, and some land uses that represent desirable locations to adults may act as barriers to children (e.g. commercial zones). To this end, we included a wider range of land uses than others have in order to provide broader applicability both to children and to more rural settings. The association is only observed in the school neighbourhood among active travellers, so could be acting via the promotion of additional travel within this setting, and may be associated with the accessibility of unmeasured facilities.

Among boys, fewer associations were detected. Higher FMI was seen in non-active travellers with major roads in the home neighbourhood. Major roads can be a deterrent to active travel (Panter, et al., 2010), and it may be that children who do not walk or cycle to school are also less likely to travel by these means to other destinations if there are major roads near their home, although why the association is in the opposite direction among active travellers is unknown. It is noteworthy that no significant relationships were seen between FMI and access to the food outlets or facilities measured here among boys.

Our results varied among groups; between girls and boys, active travellers and non-active travellers, and in different environments. Gender differences in the association between neighbourhood factors and adiposity and its determinants have been noted in past studies (Norman, et al., 2006; Singh, et al., 2010; Timperio, et al., 2008). They may reflect genuine differences in the factors driving girls' and boys' behaviour, but may also arise as a result of lack of specificity in the delineation and characterisation of neighbourhoods. In a sub-set of this sample we have seen that boys are more likely than girls to roam beyond the 800m neighbourhood boundary we used (A. P. Jones, Coombes, Griffin, & van Sluijs, 2009), and so may require different neighbourhood definitions.

As many participants lived near to their schools (57% lived within 1.6km), many school and home neighbourhoods overlap and hence associations seen for factors in the school neighbourhood may actually reflect some impact of the home environment. No significant relationships between adiposity and the route environment persist in either girls or boys after stratification by mode of travel. This could reflect the limited time children spend travelling between home and school and consequential lesser importance of this environment, or that routes have been inadequately described here.

This study has a number of strengths and weaknesses. We were able to recruit a large sample of schools and pupils, and collected detailed anthropometric measurements using standardised procedures. Anthropometry included bioelectrical impedance allowing the use of an outcome measure that has been shown to be better correlated with body fat in children than those based on weight (Tyrrell, et al., 2001). While past studies have focused on urban areas (Galvez, et al., 2009; Liu, et al., 2007; Sturm & Datar, 2005; Timperio, et al., 2010), our sample was designed to maximise environmental heterogeneity by including more rural homes and schools than are commonly studied. We also computed objective measures of a wide range of environmental variables that may be related to both physical activity and diet.

The study's weaknesses include its cross-sectional nature which means that causality cannot be inferred from the associations observed, and the large number of tests we performed means that some associations were likely to be observed by chance. Of the children invited to take part in the study, 57.0% did so. We do not have data on non-participating children with which to assess representativeness, although we do know that our sample contained a higher proportion of girls, and a lower proportion of obese children than the wider Norfolk population (van Sluijs, et al., 2008). While foot-to-foot bioelectrical impedance measures of

body fat have been shown to correlate well with those derived from dual-energy X-ray absorptiometry (Tyrrell, et al., 2001), the procedure does not measure the composition of the upper body. Nevertheless, we did test the sensitivity of the findings to different outcome measures by substituting FMI with BMI and waist circumference, and we obtained broadly similar results (not presented).

A further limitation of our study is that we cannot be sure our definition of a neighbourhood (800m around the home or school) actually reflects the area used or perceived as a neighbourhood by individuals. In a separate analysis of a sub-sample of 100 of the SPEEDY participants, global positioning systems devices were worn by children at the same time as accelerometers, and showed that 63% of all bouts of physical activity took place within the 800m home neighbourhood (A. P. Jones, et al., 2009). The routes to school we delineated were based on shortest network distance between a participant's home and school. This definition has been used elsewhere (Timperio, et al., 2006), but it may not necessarily represent the route actually taken by children, especially for those travelling by car, bus or train, and we did not have any data with which to test the validity of these routes. Our data on the location and classification of food outlets and physical activity facilities came from a national commercial database, and while the spatial coverage is reportedly high (Ordnance Survey, 2007d), no work has been published that assesses its validity. There is evidence from similar datasets in the USA that completeness varies by the SES of neighbourhoods so that in poorer areas outlets or facilities are less likely to be recorded (Rundle, et al., 2009). To our knowledge there has been no assessment of any variations in the completeness of the POI database we used, although if a social bias does exist differences may be less pronounced in our relatively affluent study area. We were also unable to test the validity of the classification scheme used in the POI data, for example how an outlet listed as a fast-food restaurant was defined as such, but we believe the use of broad categories of outlets and facilities reduces the potential for misclassification.

Associations between certain components of the environment and adiposity may be weak, and while they may be important at the population level, more accurate definition and measurement of the environment, and larger sample sizes may be required to detect them. Furthermore, the heterogeneity in exposure to the different environmental measures in our cross-sectional sample may be low relative to the changes that have occurred in the characteristics of environments over time, thereby limiting our ability to detect associations with adiposity. It is also noteworthy that schools in Norfolk, and consequently our sample, have a low proportion of non-white pupils, which may also limit the generalisability of our findings to other populations.

In conclusion, this study found some associations between FMI and characteristics of home and school environments, with most associations observed in girls. Further investigative work, preferably with longitudinal data, is required to establish the relative importance of different environments on the causation of obesity among 9-10 year old children, and why the impact of environmental factors may differ between girls and boys.

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Table 1

Details of environmental variables, and characteristics of home, school and route environments

				Summary (mean (standard deviation))		
Variable	Description - Neighbourhoods	Description – Routes	Source	Home	School	Route
Access to facilities:						
Healthy food outlets	An inverse distance weighted sum of distance to all outlets/facilities within 6km of home/school	Number of outlets/ facilities along the route, divided by route length	A	4.24 (10.85)	3.91 (9.60)	0.17 (0.61)
Unhealthy food outlets				24.42 (48.36)	27.57 (45.93)	0.85 (1.87)
Physical activity facilities				23.7 (40.10)	44.69 (62.79)	0.8 (2.96)
Accessible open land	Area of accessible land within the neighbourhood as a percentage of total neighbourhood area	Area of accessible land along the route, divided by route length	A, B, C, D, E	2.47 (6.55)	2.23 (5.87)	1.42 (4.39)
Road safety:						
Density of serious and fatal road traffic accidents	Number of serious or fatal road traffic collisions in the neighbourhood 2002-2005 divided by total length of roads with the neighbourhood	Number of serious or fatal road traffic collisions along the route 2002-2005, divided by route length	F	0.29 (0.33)	0.28 (0.30)	0.13 (0.33)
Proportion of roads that are major roads	Length of major roads within the neighbourhood, divided by total length of roads within the neighbourhood	Proportion of the route that is along a major road	G	0.06 (0.09)	0.07 (0.08)	10.94 (21.12)
Density of verges (roadside access with natural surface)	Area of verges within the neighbourhood, divided by neighbourhood area	Area of verges along the route, divided by route length	B	2.31 (1.37)	1.83 (0.97)	4.71 (3.71)
Street connectivity:						
Effective walkable area & Route length ratio	Effective walkable area: ratio of the area within an 800m walking distance of a location to the total area within an 800m radius of the location	Route length ratio: ratio of length of route to the straight-line distance between home and school	G	0.42 (0.16)	0.51 (0.13)	0.70 (0.17)
Connected node ratio	Ratio of junctions to junctions and cul-de-sacs	n/a	G	0.78 (0.07)	0.71 (0.09)	n/a
Land use mix:						
Herfindahl- Hirschmann Index ^a	The sum of squares of the percentage of each land use type in the neighbourhood	The sum of squares of the percentage of each land use type along the route	B, H	2994 (1448)	2642 (1036)	3460 (983)

Data Sources: A = Ordnance Survey (OS) Points of Interest (Ordnance Survey, 2007d), B = OS MasterMap (Ordnance Survey, 2007b), C = Forestry Commission, D = Royal Society for the Protection of Birds, E = Woodland Trust, F = Norfolk & Suffolk Constabularies, G = OS Integrated Transport Network (Ordnance Survey, 2007a), H = Land Cover 2000 (Centre for Ecology and Hydrology, 2000)

^aSeventeen different land uses were classified: farmland, woodland, grassland, uncultivated land, beach, marshland, sea, small settlement, private gardens, parks, residential, commercial, multiple use buildings, other buildings, unclassified buildings, other urban and roads. Method developed by Song & Rodriguez (2005)

Table 2

Characteristics of study participants

		<u>Count(%), or Median, IQR unless otherwise stated</u>		
		<u>All</u>	<u>Girls</u>	<u>Boys</u>
Number of cases		1995	1103	892
Age (years; mean, SD)		10.25, 0.31	10.26, 0.31	10.24, 0.31
Fat Mass Index ^a		5.16, 3.97 - 7.01	5.62, 4.54 - 7.64	4.51, 3.44 - 6.13
Parent's highest educational qualification	None	137 (6.9%)	80 (7.3%)	57 (6.4%)
	GCSE or equivalent	1103 (55.3%)	611 (55.4%)	492 (55.2%)
	A'Level or equivalent	457 (22.9%)	258 (23.4%)	199 (22.3%)
	Degree or higher	298 (14.9%)	154 (14%)	144 (16.1%)
Mode of travel to school	on foot ^a	800 (40.1%)	487 (44.2%)	313 (35.1%)
	bicycle ^a	185 (9.3%)	69 (6.3%)	116 (13.0%)
	bus/train	123 (6.2%)	64 (5.8%)	59 (6.6%)
	car	887 (44.5%)	483 (43.8%)	404 (45.3%)

^a difference between girls and boys statistically significant $p < 0.05$

Table 3

Results from multiple regression models of log-transformed FMI for girls, in home, school and route environments, stratified by mode of travel to school

		Car, Bus or Train (n=547)				Walk or Cycle (n=556)			
		β^a	95%CI		% difference in predicted FMI b	β^a	95%CI		% difference in predicted FMI b
			lower	upper			lower	upper	
Home									
Age		0.054	-0.050	0.158	-7.11%	0.100	-0.001	0.201	13.68%
Parent's highest educational qualification	GCSE or equivalent d	-0.121	-0.265	0.023	-11.37%	-0.093	-0.207	0.020	-8.92%
	A'Level or equivalent d	-0.148	-0.299	0.002	-13.79%	-0.168**	-0.292	-0.043	-15.43%
	Degree or higher d	-0.120	-0.281	0.040	-11.33%	-0.174*	-0.310	-0.039	-16.00%
Access to healthy food outlets	middle e	-0.109*	-0.191	-0.026	-10.30%	-0.138**	-0.223	-0.052	-12.87%
	top - best access e	-0.082	-0.185	0.021	-7.89%	-0.149**	-0.246	-0.052	-13.81%
Access to unhealthy food outlets	middle e	0.071	-0.027	0.169	7.38%	0.075	-0.020	0.171	7.82%
	top - best access e	0.124*	0.014	0.234	13.17%	0.133*	0.023	0.243	14.28%
Accessible open land area	middle e	-0.006	-0.102	0.090	-0.60%	0.075	-0.035	0.184	7.74%
	top - highest % e	0.050	-0.021	0.122	5.14%	0.020	-0.052	0.093	2.07%
Land Use Mix c	middle f	-0.037	-0.127	0.052	-4.12%	0.002	-0.085	0.090	0.25%
	bottom - greatest mix f	0.005	-0.092	0.102	-0.47%	0.027	-0.067	0.121	2.74%
School									
Age		0.047	-0.058	0.153	-6.27%	0.103*	0.002	0.205	14.12%
Parent's highest educational qualification	GCSE or equivalent d	-0.107	-0.251	0.037	-10.15%	-0.103	-0.217	0.011	-9.81%
	A'Level or equivalent d	-0.139	-0.291	0.014	-12.94%	-0.177**	-0.302	-0.053	-16.24%
	Degree or higher d	-0.101	-0.262	0.060	-9.59%	-0.193**	-0.329	-0.057	-17.59%
Access to healthy food outlets	middle e	-0.035	-0.120	0.050	-3.44%	-0.019	-0.116	0.078	-1.89%
	top - best access e	0.021	-0.068	0.110	2.11%	-0.089	-0.183	0.006	-8.51%
Access to unhealthy food outlets	middle e	0.006	-0.098	0.110	0.58%	0.120	-0.014	0.254	12.76%
	top - best access e	0.012	-0.107	0.130	1.17%	0.144*	0.009	0.280	15.50%
Accessible open land area	middle e	-0.033	-0.147	0.081	-3.21%	0.047	-0.059	0.152	4.77%
	top - highest % e	0.017	-0.059	0.094	1.77%	0.078*	0.005	0.151	8.08%
Land Use Mix c	middle f	-0.086	-0.185	0.012	-8.34%	-0.150*	-0.268	-0.031	-13.92%
	bottom - greatest mix f	0.001	-0.112	0.113	-0.06%	-0.124	-0.249	0.001	-11.67%
Route									
Age		0.056	-0.049	0.161	7.90%	0.100	-0.002	0.202	13.68%
Parent's highest educational qualification	GCSE or equivalent d	-0.113	-0.257	0.031	-10.69%	-0.090	-0.204	0.025	-8.56%
	A'Level or equivalent d	-0.152	-0.303	0.000	-14.08%	-0.171**	-0.296	-0.046	-15.72%

		Car, Bus or Train (n=547)				Walk or Cycle (n=556)			
		B ^a	95%CI		% difference in predicted FMI ^b	B ^a	95%CI		% difference in predicted FMI ^b
			lower	upper			lower	upper	
Access to healthy food outlets	Degree or higher ^d	−0.110	−0.271	0.051	−10.38%	−0.175 [*]	−0.312	−0.039	−16.09%
	present ^g	−0.021	−0.104	0.062	−2.10%	−0.032	−0.143	0.078	−3.18%
Access to unhealthy food outlets	present ^g	0.041	−0.029	0.110	4.16%	0.007	−0.068	0.082	0.70%
Accessible open land area	present ^g	−0.003	−0.069	0.063	−0.31%	0.065	−0.015	0.146	6.77%
Land Use Mix ^c	middle ^f	0.047	−0.032	0.127	4.84%	0.026	−0.053	0.105	2.63%
	bottom - greatest mix ^f	0.064	−0.013	0.141	6.65%	0.033	−0.050	0.117	3.38%

** = p<0.01,

* = p<0.05

^a unstandardised co-efficients,

^b % difference in predicted FMI across range of data (continuous variables), or between category and base category (categorical variables),

^c Higher values of the Herfindahl- Hirschmann Index indicate lower land use mix

^d Base categories: none/school leaving certificate,

^e bottom tertile,

^f top tertile,

^g not present

Table 4

Results from multiple regression models of log-transformed FMI for boys, in home, school and route environments, stratified by mode of travel to school

		Boys							
		Car, Bus or Train (n=463)				Walk or Cycle (n=429)			
		B ^a	95%CI		% difference in predicted FMI ^b	B ^a	95%CI		% difference in predicted FMI ^b
			lower	upper			lower	upper	
Home									
Age		0.037	-0.086	0.160	5.39%	0.038	-0.084	0.161	7.41%
Parent's highest educational qualification	GCSE/equivalent ^c	-0.213 [*]	-0.380	-0.047	-19.22%	-0.059	-0.208	0.091	-5.71%
	A'Level/equivalent ^c	-0.291 ^{**}	-0.468	-0.113	-25.23%	-0.092	-0.254	0.071	-8.77%
	Degree or higher ^c	-0.238 [*]	-0.421	-0.056	-21.20%	-0.088	-0.259	0.084	-8.40%
Major roads in neighbourhood	present ^d	0.109 ^{**}	0.031	0.187	11.53%	-0.066	-0.145	0.013	-6.39%
School									
Age		0.039	-0.085	0.163	5.68%	0.040	-0.083	0.162	7.70%
Parent's highest educational qualification	GCSE/equivalent ^c	-0.210 [*]	-0.378	-0.043	-18.96%	-0.053	-0.202	0.095	-5.19%
	A'Level/equivalent ^c	-0.292 ^{**}	-0.471	-0.113	-25.32%	-0.088	-0.250	0.073	-8.47%
	Degree or higher ^c	-0.247 ^{**}	-0.431	-0.063	-21.91%	-0.089	-0.260	0.083	-8.48%
Major roads in neighbourhood	present ^d	0.026	-0.051	0.104	2.67%	-0.086 [*]	-0.167	-0.005	-8.25%
Route									
Age		0.037	-0.087	0.160	5.41%	0.029	-0.094	0.152	5.50%
Parent's highest educational qualification	GCSE/equivalent ^c	-0.220 [*]	-0.387	-0.053	-19.75%	-0.042	-0.191	0.107	-4.11%
	A'Level/equivalent ^c	-0.306 ^{**}	-0.485	-0.128	-26.38%	-0.070	-0.232	0.092	-6.79%
	Degree or higher ^c	-0.260 ^{**}	-0.443	-0.076	-22.88%	-0.075	-0.247	0.097	-7.22%
Major roads on route	present ^d	0.067	-0.010	0.144	6.91%	0.044	-0.045	0.134	4.52%

^{**} = p<0.01,

^{*} = p<0.05

^a unstandardised co-efficients,

^b % difference in predicted FMI across range of data (continuous variables), or between category and base category (categorical variables)

^c Base categories: none/school leaving certificate,

^d not present